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(54) Stereophonic binaural recording or reproduction method for headphones

(57) The signals L of the left stereo channel are supplied to the left ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the left of the centre-plane, and to the right ear, weighted in unit 10 with the outer ear transmission function associated therewith for the same range of angles. In addition, delayed signals of the left stereo channel are supplied, with a delay lying clearly outside the range of sum location and of the audible echo - i.e., between 5 ms and 80 ms - to the right ear, weighted with the outer ear transmission function associated therewith for the opposite range of angles. The signals R of the right stereo channel are supplied to the right ear and left ear in the same way with lateral inversion in respect of the centre-plane, necessary corrections of the amplitude response with frequency being made by means of linear-phase digital filters to the particular outer ear transmission functions used without affecting the time structures.

This is intended to ensure that the correct location of quite definite sound sources can be made quite clearly.

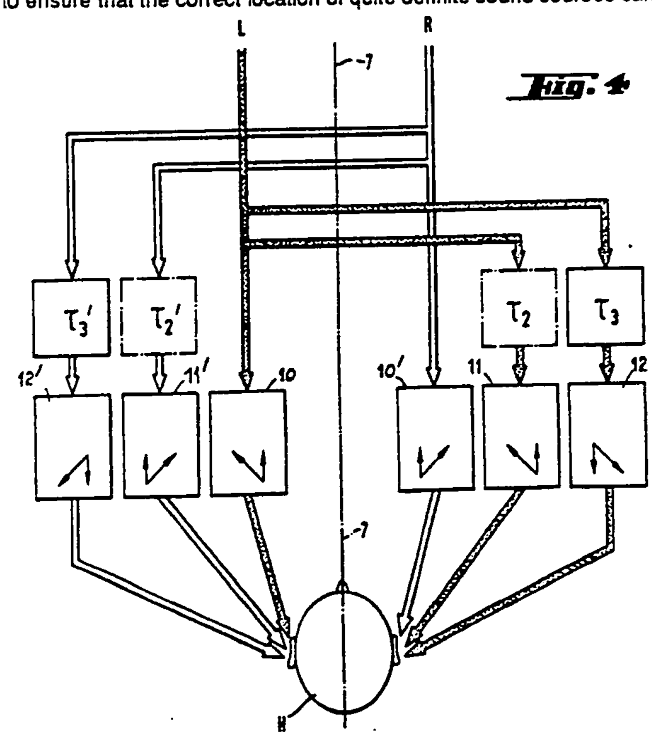

Fig. 4

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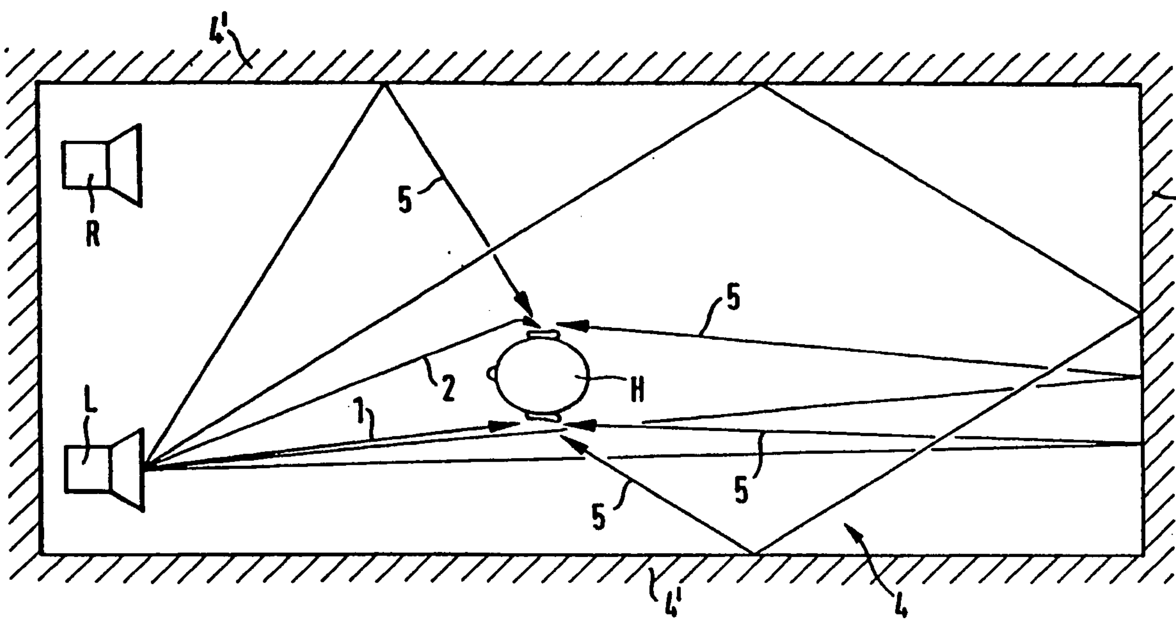

Fig. 1

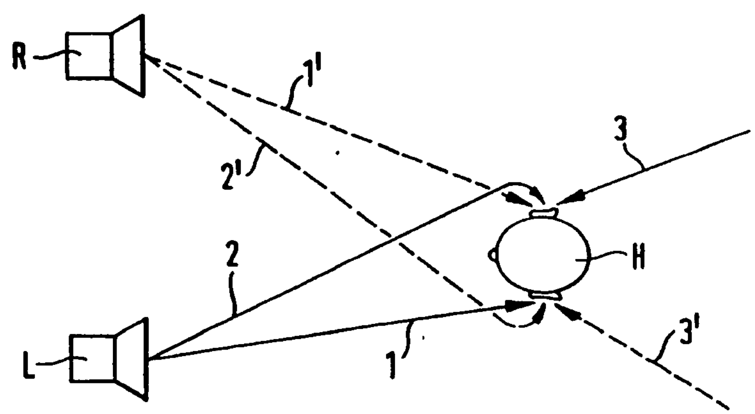

Fig. 2

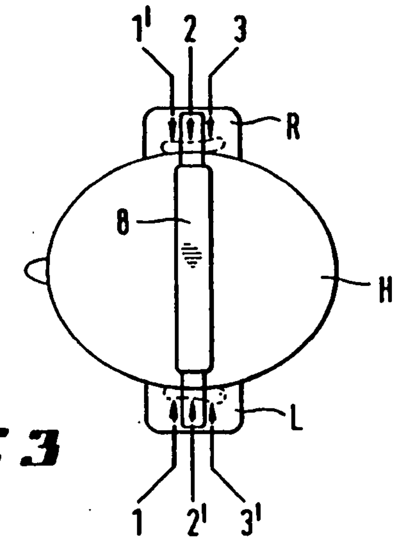

Fig. 3

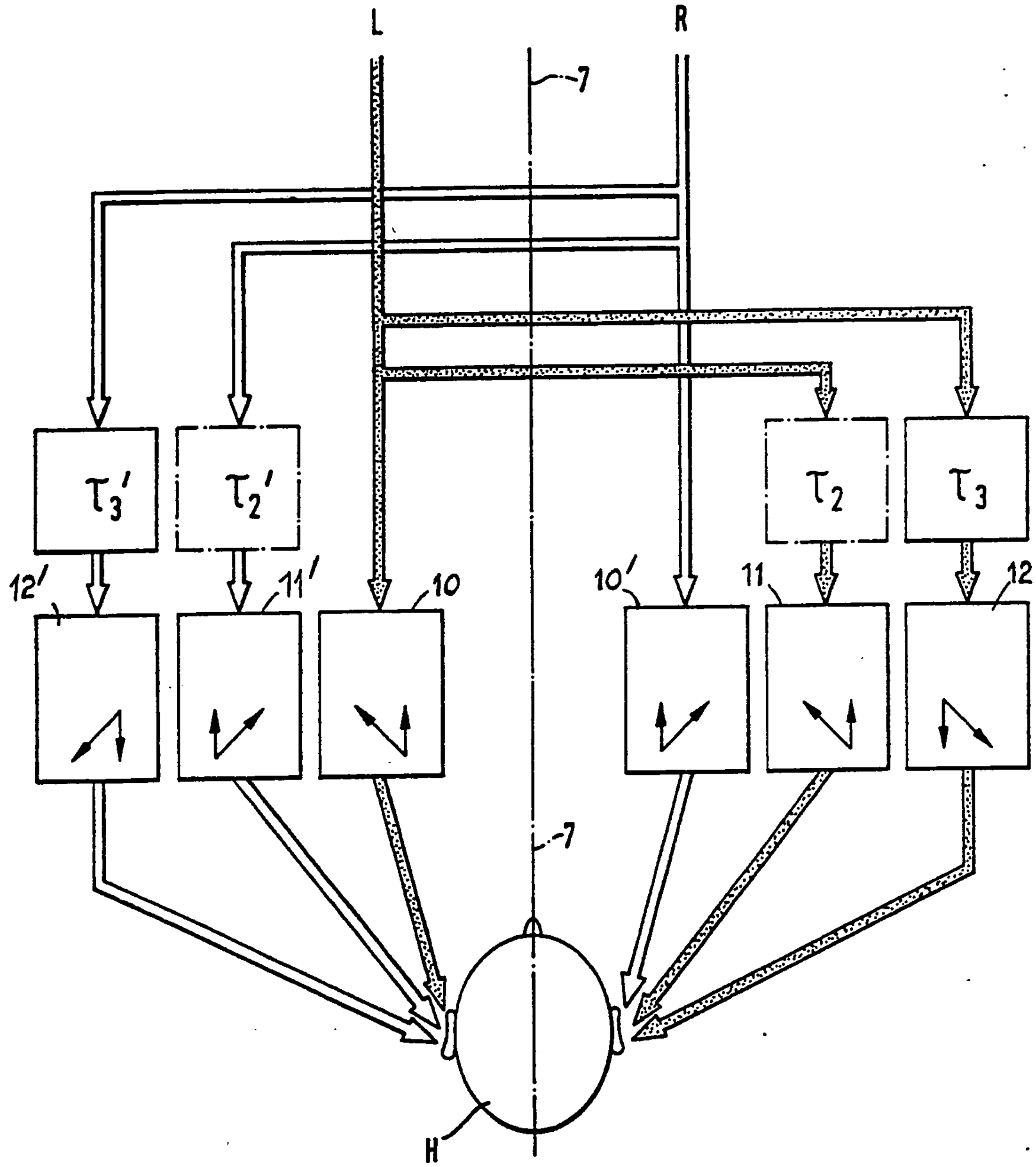

Fig. 4

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PATENTS ACT 1977

P6120GB/ALM/mkf

Description of Invention

"Stereophonic binaural recording or reproduction method"

THE INVENTION relates to a stereophonic binaural recording or reproduction method for audio signals presented by way of headphones.

Many stereophonic recording and reproduction methods endeavour faithfully to reproduce at the listening place the original listening event at the recording place. DE OS 3 112 874 discloses one such method of reproducing a sound recording and an apparatus for performing the method, the aim being to achieve a very natural multidimensional sound reproduction, more particularly when headphones are the sound-reproducing means. The basis of the method is that the sound recording is supplied to the reproducing apparatus by way of an echo generator producing, within a period of approximately 50 ms after arrival of the direct sound pulse, echo reflections at such time intervals, preferably more than 2 ms, that the listener perceives them as loud individual reflections, at least some of which consist of two pulses triggered by a direct sound pulse from a recording channel, the first of the two pulses being delivered to the reproducing apparatus by way of the reproduction channel associated with the corresponding recording channel while the second such pulse is weaker than the first and is delivered through the other channel of the reproducing apparatus with a delay of approximately from 0.2 to 1 ms, preferably 0.63 ms, after the first pulse, the echo reflections being attenuated in dependence upon tone frequency.

This method, called real time stereophony, is based on the knowledge that it is not readily possible to transmit sound fields in their original spatial distribution to a listening space different from the recording space. An electroacoustically simulated sound field must be presented on the basis of psychoacoustic considerations, more particularly in the case of reproduction by headphones where there is no co-operating acoustic listening chamber. The sound material used for this purpose is defined in space at least from its recording. This method therefore helps to provide in reproduction an enhanced stereophonic effect and excellent transparency of a sound event, more particularly of a music event, since the main spatial reflections are simulated with a subsequent echo in the acoustically correct time range. However, this method does not solve the problem of mis-location of the hearing events.

This invention aims to provide a method for the stereophonic binaural recording or reproduction of audio signals such that the original sound event is faithfully reproduced at the listening place and more particularly that the correct location of quite definite sound sources can be made quite clearly.

Accordingly, the invention provides a stereophonic binaural recording or reproduction method for audio signals presented by way of headphones, comprising supplying to the left ear the signals of the left stereo channel weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the left of the centre-plane, supplying to the right ear the signals of the left stereo channel weighted with the outer ear transmission function associated therewith for the same range of angles, additionally supplying to the right ear delayed signals of the left

stereo channel with a delay lying clearly outside the range of sum location and the audible echo and weighted with the outer ear transmission function associated therewith for the opposite range of angles, and supplying the signals of the right stereo channel to the right ear and left ear in the same way with lateral inversion in respect of the centre-plane, necessary corrections of the amplitude response with frequency being made by means of linear-phase digital filters to the particular outer ear transmission functions used without affecting the time structures.

The essence of the invention can be regarded as being that the location of particular sound sources within a listening room or space is possible more particularly because, when the individual sound events perceived by the ear are processed in the brain, the first reflection from the mirror sound source is particularly significant for the ear. Quite generally, directional and distance hearing is determined acoustically on the basis of the outer ear transmission function. As a backup to this, the brain, acting like a computer, draws on optical impressions and turning, nodding and tilting movements of the head in the final determination of direction in order to sense the actual spatial acoustic circumstances. Existing knowledge about the signal may also come into play. So that all these perceptions are linked together logically, the brain needs a long store and a short store, the latter continuously being adapted to the ever-changing instantaneous situation. In the case of contradictory perceptions, for example, if the optical impression does not match the spatial circumstances, the audio signal is located to the rear. This is probably plausible as being a protective function of human beings.

According to the invention, a normal sound

recording for stereophonic loudspeaker reproduction is presented vary faithfully by way of headphones when in addition to the directly arriving audio signals of the two channels on the left and on the right the spatial reflections of the listening area are simulated but weighted with the direction-dependent outer ear transmission functions. Integrating the outer ear transmission function for all room directions leads to a substantially smooth amplitude response with frequency for the ear. In practice, however, a complex simulation of this nature is impossible and so recourse must be had to a simplified configuration.

Resulting from a large number of listening tests it finally proved possible to reach this very simplified configuration ensuring correct and fruitful results. This means that only three different audio signals need to be presented to each ear in order to guarantee a faithful hearing event.

According to a preferred feature of the invention, the necessary correction of distortion takes the form of inverse linear phase summation of the outer ear transmission functions associated with each ear.

To ensure auditory faithfulness to the original, two particular problems need to be borne in mind, namely:

1. Correction of the offered audio signals for distortion, and

2. Consideration of possibly individual differences in the outer ear transmission functions of different people.

Since audio signals corresponding merely to three directions are presented to each ear, the sum of these

signals does not give a smooth amplitude characteristic with frequency. The frequency characteristic, whose amplitude pattern varies very considerably, leads to sound discolorations. To solve this problem the outer ear transmission functions corresponding to each ear are summed, then each individual outer ear transmission function is multiplied by the inverse linear phase sum outer ear transmission function. This has two results. First, the sound colours remain because the sum of the amplitude characteristics with frequency is smooth, and second the phase structures and, therefore, the time structures of the audio signal are unaffected, with the result more particularly that directional hearing in the front range of angles of $\pm 60^{\circ}$ (to the left and right of the centre-plane) is unaffected.

The problem of individual differences between individuals cannot be completely solved. Although linear-phase correction of the outer ear transmission function compensates for individual variations in frequency characteristics, differences still remain in the individual phase structures. The only choice remaining is, therefore, to use the outer ear transmission function of a very good "average person" or to present those of "various people". The final remaining difference between the possible choice coming closest to individual hearing can be corrected only by means of the individual learning ability of the listener. The best listening results are of course obtained with one's "own ears" - i.e., with one's own outer ear transmission functions. It was found in practical listening testing that when the subjects under test listened with "foreign ears" with their head fixed, they found it impossible to distinguish whether the audio signals were coming from loudspeakers or headphones. Front/rear direction inversions occurred with both loudspeaker and headphone presentation but in no case did

the familiar in-the-head location occur.

Another advantageous feature of the invention is that the left stereo signals supplied to the right ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the left of the centre-plane, and the right stereo signals supplied to the left ear, weighted with the outer ear transmission functions associated therewith for the range of angles between 0° and 45° on the right of the centre-plane, are delayed by a time of at most 700 µs.

A time delay of the audio signals mentioned enhances the interaural signal differences and therefore strengthens the overall effect of the method according to the invention or it can be used with reference to the signal to control base width.

According to another feature of the invention, the left stereo signals supplied to the right ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the left of the centre-plane, and the right stereo signals supplied to the left ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the right of the centre-plane, together with the already originally delayed signals, may be presented alternately in pairs with unequal delays within the said time ranges.

The dissimilar delay of the various stereo signals takes account of geometric assymetries of the human head and of the listener regarding his location in a walled space. The naturalness of the hearing event presented is very strongly realised in this way. Delay times of, for example, approximately 0.3 ms for the left ear and

approximately 0.4 ms for the right ear have proved very advantageous for the interaural signal component. Correspondingly, the delay times corresponding to a mirror sound source for the left ear should be approximately 27 ms for the left ear and approximately 22 ms for the right ear. Other combinations are possible and depend upon individual circumstances.

The method according to the invention can in principle be used for recording and reproduction. There are still some outstanding questions regarding the compatibility of the method with loudspeaker reproduction.

In order that the invention may be more readily understood, an embodiment thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates the listening event in a closed reflecting room;

Figure 2 shows the sound components which are important for listening which is faithful to the original;

Figure 3 shows the audio signals important for headphones listening which is faithful to the original; and

Figure 4 shows the audio signals to be presented to the ear in accordance with the invention, including the means necessary for the method.

Figure 1 shows the sound conditions in the case of stereophonic listening in a closed room having sound-reflecting walls. Sound waves - i.e., audio signals - from a left loudspeaker L reach the listener's left and

right ears both directly and by way of reflections from the walls, floor and ceiling of the room. Similar considerations apply to the same extent and simultaneously to a right loudspeaker R. Each direction is weighted with its associated outer ear transmission function; the components of the lateral reflections and the ceiling reflections basically transmit the stereophony while the primary signals reaching the ear directly from the two loudspeakers convey the direction from which the supposed sound event is coming. The hearing interprets direction according to the law of sum location and the first wave front. According to the invention, however, directional hearing is enhanced very considerably by the first reflection from the direction of a mirror sound source to reach the ear from the rear and side thereof or completely from the rear thereof. The entire outer ear transmission function integrated by the ear over all room directions has a smooth amplitude response with frequency. Such a complex simulation is virtually impossible in practice, and so the method according to the invention is based on a very simplified configuration of those sound components which are important contributors to directional hearing.

Figure 2 shows which sound components are important contributors to accurate directional hearing. A sound event radiated by the left loudspeaker L and right loudspeaker R reaches the left ear by the shortest possible distance 1 and the right ear by the shortest possible distance 1'. The signal of the left loudspeaker L, subject to the interaural transit time and to distortions caused by the head, reaches the right ear along path 2 and the signal of the right loudspeaker R reaches the left ear along path 2'. The laws of sum location and of the first wave front are therefore complied with. Nevertheless, accurate directional hearing, more particularly in live rooms, is not

definitely guaranteed. The third signal 3; 3' according to the invention, corresponding to the reflection from a mirror sound source, is necessary for directional faithfulness.

When, as shown in Figure 3, these three signals are presented to the ear by way of headphones with the outer ear transmission function of the corresponding directions, the three main signals for the left and right ear having the references 1, 2', 3' and 1', 2, 3, the problems of correct equalisation and of individually different outer ear transmission functions of different persons cannot be neglected.

The method according to the invention of presenting stereophonic binaural audio signals by way of headphones is shown in Figure 4. The audio signal of the left stereo signal L is first supplied to the left ear directly, weighted with the outer ear transmission function associated therewith, for the range of angles between 0° and 45° on the left of the centre plane (indicated in Figure 4 by the block 10 with the corresponding angle vectors). The same audio signal reaches the right ear by way of two delayed branches. In one branch the delay $_2$ is up to 700 µs, the audio signal being weighted with the outer ear transmission function associated with the right ear for the range of angles between 0° and 45° on the left of the centre-plane. This branch takes interaural listening into consideration.

In the second delay branch the delay times $_3$ are between 5 ms and 80 ms, weighted with the outer ear transmission function associated with the opposite range of angles for the right ear. The corresponding weighting with the associated outer ear transmission functions is denoted by the blocks 11 and 12 with the corresponding vectors in the drawing. The same conditions as apply to

the right and left ear apply with lateral inversion, referred to the centr -plane, to the audio signal of the right receiver R. In this case the delays have the reference τ'_2 and τ'_3 and the weighting means have the reference 10', 11' and 12'. For increased directional orientation the various delays are presented in pairs and unequally. For example, τ_3 can be 27 ms and τ_2 0.3 ms, in which case it is advantageous if τ'_3 is 22 ms and τ'_2 is 0.4 ms. It would be inadvisable to present another delayed audio signal appearing to some extent as first echo of a mirror sound source to the left ear as well as to the right ear and vice versa since it leads to acoustic blocking of the ear therefore nullifies the effect achievable by the method according to the invention. Figure 4 does not show the necessary linear phase equalization which maintains the sound colours and leaves the phase structures of the outer ear transmission functions unaffected.

CLAIMS:

1. A stereophonic binaural recording or reproduction method for audio signals presented by way of headphones, comprising supplying to the left ear the signals of the left stereo channel weighted with the outer ear transmission function associated therewith for the range of angles between 0^o and 45^o on the left of the centre-plane, supplying to the right ear the signals of the left stereo channel weighted with the outer ear transmission function associated therewith for the same range of angles, additionally supplying to the right ear delayed signals of the left stereo channel with a delay lying clearly outside the range of sum location and the audible echo and weighted with the outer ear transmission function associated therewith for the opposite range of angles, and supplying the signals of the right stereo channel to the right ear and left ear in the same way with lateral inversion in respect of the centre-plane, necessary corrections of the amplitude response with frequency being made by means of linear-phase digital filters to the particular outer ear transmission functions used without affecting the time structures.

2. A method according to claim 1, wherein the necessary correction of distortion takes the form of inverse linear phase summation of the outer ear transmission functions associated with each ear.

3. A method according to claim 1 or 2, wherein the left stereo signals supplied to the right ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0^o and 45^o on the left of the centre-plane, and the right stereo signals supplied to the left ear, weighted with the outer ear transmission functions associated therewith for the

range of angles between 0° and 45° on the right of the centre-plane, are delayed by a time of at most 700 µs.

4. A method according to claim 1 or 2, wherein the left stereo signals supplied to the right ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the left of the centre-plane, and the right stereo signals supplied to the left ear, weighted with the outer ear transmission function associated therewith for the range of angles between 0° and 45° on the right of the centre-plane, together with the already originally delayed signals, are presented alternately in pairs with unequal delays within the said time ranges.

5. A stereophonic binaural recording or reproduction method for audio signals presented by way of headphones, substantially as hereinbefore described with reference to the accompanying drawings.

6. Any novel feature or combination of features described herein.

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